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QUEENSLAND.

REPORT ON SCHEME FOR THE ABATEMENT OF
FLOODS IN THE BRISBANE RIVER.

Presented to both Houses of Parliament by Command.

THE HONOURABLE THE TREASURER, BRISBANE.

Brisbane, 27th November, 1899.

SIR,—Herewith I beg to forward my Report on the Brisbane River.

I have, &c.,

JOHN PENNYCUICK.

The question which has been submitted to me for report is one of extreme difficulty, on account of the large quantity of water to be dealt with, and the impossibility of adequately enlarging the waterway of that portion of the river which runs through the city of Brisbane, except at an inordinate expense, the result of which would be after all somewhat problematical.

Fortunately the difficulty of arriving at a sound conclusion is very much reduced by the admirable manner in which the physical and historical facts have been placed on record by the Water Supply Department of the Queensland Government, the report of whose Hydraulic Engineer, dated 10th June, 1896, I propose to take as the text and to a great extent as the basis of this Report.

It is not necessary to dwell upon the injury which has been done to the interests of the colony, and especially of its capital city, by the floods in the river in question, and I propose therefore to pass at once to the measures which are proposed for the mitigation of these floods.

Mr. Henderson's Report deals with various schemes which have been proposed with this object, all of which are condemned by him, a condemnation in which, with one reservation, I fully concur.

Chief among them are alternative proposals for two diversion canals—one to be taken from the river about four and a half miles above the Victoria Bridge, and the other about eight miles higher up, and both discharging into the sea at the mouth of Tingalpa Creek.

Each of these works would be enormously costly, and, without going so far as to endorse Mr. Henderson's estimate of seven millions of pounds for the shorter, and nine and a half millions for the longer canal (estimates which I have hardly sufficient information to criticise), there can be no doubt that either would cost a sum far in excess of what is required to attain the object by other means, and the expenditure of which would only be justified by complete success.

In addition to their cost there is an objection to schemes of this class which Mr. Henderson has not noticed (probably because he considered it unnecessary), but which is in my opinion almost fatal.

The Brisbane River is a navigable one, and it is, I understand, contemplated to improve its channel so as to make it available for vessels of a larger class than those which use it at present. As Mr. Henderson rightly states, this question is separate from that of the mitigation of floods, but it must nevertheless be borne in mind in considering the effect of a scheme having the latter object in view. It might well be found that the object had been dearly bought if part of the price paid was a substantial reduction of the usefulness of the river for navigation.

I am strongly of opinion that the action of the natural discharge of a river is a powerful factor (much more powerful than is generally supposed) in keeping open its mouth and preventing the formation of a bar thereat—a consideration which will be apparent to anyone who knows how quickly the mouths of rivers in the South of India, all but the largest of which are practically dry for part of the year, close up during the dry season.

Any measures which tend to reduce the total amount of water brought down by a river must be looked upon with the gravest distrust upon this account, and nothing short of absolute necessity, apart from any question of cost, should induce the adoption of such measures.

Similar objections apply to the idea of a diversion canal higher up the river, discharging into a separate drainage basin from that of the Brisbane.

I am bound to add that there is no evidence to show that such a scheme as this is possible at all, even at a prohibitive cost; while, as Mr. Henderson correctly points out, it would be only a very partial mitigation, and would certainly give rise to conflict in connection with the transfer of water from one drainage basin to another.

Except as to one or two entirely unessential points in regard to matters of detail, I agree cordially with every word of this section of Mr. Henderson's Report, and also, to a great extent, with his views as to embankments or levees.

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The next section, on "compensating or regulating reservoirs," is that alluded to above, in connection with which I find myself unable to agree with Mr. Henderson. As the construction of a large reservoir of this class will form an essential part of my proposals, it will be more convenient to defer consideration of the question for the present. I will merely observe here that I think Mr. Henderson has considerably over-estimated the quantity of water which it would be necessary to store, and has at the same time somewhat over-rated the difficulties attaching to the construction of works of this class.

Another scheme, not alluded to in Mr. Henderson's Report, is contained in a letter from Mr. R. M. Stuart, a copy of which has been forwarded to me for information. This consists of a diversion canal taken off from the left bank of the river near the old cemetery and rejoining it near the mouth of Breakfast Creek, thus relieving the worst portion of the river bed.

Concerning this scheme I can only say that I consider the idea a very good one, and it will be seen from the preliminary note submitted by me in October, 1893, that a similar canal would form, under certain contingencies, a portion of the work which I should recommend.

My own idea was to make the diversion on the right bank, taking off from the river and rejoining it a little higher than that recommended by Mr. Stuart, but I had then no information as to levels of the ground through which this canal would pass, and after an inspection of both lines, I am inclined to think that on the whole the line which I selected would be the best, though without regular surveys I cannot speak positively.

It would, however, be very costly, and would at best give only a partial relief, and must be combined with other measures to produce the full effect required, and with the information now at my disposal, I am able to say that any diversion canal will be unnecessary.

With regard to Mr. Henderson's own schemes, described in detail on pages 9 to 13 of his Report, I can only say that they appear, except on one point, to be thoroughly well thought out, and that if I could agree with the proposition from which he starts—that a regulating reservoir is impracticable—I should say that no better mode of dealing with the difficulty could be adopted, provided his scheme was supplemented by one or other of the short diversion canals mentioned above. This would be absolutely necessary, because I am certain that Mr. Henderson, like many others who have discussed this question, has over-estimated the relief to be obtained by dredging. The greater part of the increased area of waterway thus given is below mean sea-level, and is exceedingly inefficient as regards discharging power. I shall have to refer to this subject again, but may say now that I very much doubt whether the improvements proposed by Mr. Henderson would have the effect of lowering the flood-level so much as he calculates, even if combined with a considerable improvement of the river-bed above the Victoria Bridge, and am quite certain that they would not do so without this improvement. What their actual effect would be is by no means an easy matter to calculate; in fact, must, until brought to the test of experience, remain largely a matter of opinion, but it would be certainly less than Mr. Henderson supposes.

Widening the river bed would no doubt give the desired relief, but the cost of widening to the extent required in the portion where it is most necessary, would be so great as to be prohibitory. There is, moreover, one very serious objection to any attempt at providing for abnormal floods in a river by enlargement of its bed, and that is that the bed so enlarged is too wide for its work in ordinary years—that is, in nineteen years out of twenty—and there will be an irresistible tendency to silt up, a tendency which will be increased where the river is open to tidal influence, involving a constant expenditure on dredging if the full waterway is to be available in those abnormal years when it is wanted. This objection applies, to some extent, to diversion canals, as well as to actual enlargement of the river bed.

I cannot agree in the advocacy of "walling" which forms an important part of each of Mr. Henderson's schemes, and is alluded to as a possible substitute for all of them. I think it would be found that in this case the remedy would be worse than the disease.

Since my arrival here a number of schemes, mostly by amateurs with absolutely no knowledge of the conditions to be satisfied, have been placed before me, verbally or in writing; but none of them deserve serious criticism.

All these schemes, as well as all others dealing only with the lower part of the river, have the defect that they relieve only the city of Brisbane and its immediate neighbourhood, and though this is undoubtedly the most important of the objects to be obtained, it is impossible to read the account of the damage done by floods in the upper part of the river, without a conviction that as far as possible any measures to be adopted should deal with the river as a whole, and not merely with its tidal compartment.

This conviction has been greatly strengthened by the inspection which I have made of the greater part of the river valley, from the junction of the Stanley and Brisbane rivers to the city of Brisbane. Until I had made this inspection I had no idea how urgent was the necessity for relief of this part of the river, quite independently of the interests of the city. A very careful study of the whole of the facts, and an inspection of the localities affected, has convinced me that the difficulty cannot be completely met except by a substantial reduction of the maximum quantity of water passing down the river at a given time, and this can only be done either by a diversion canal or by a regulating reservoir which will hold back a portion of the river water and let it down gradually as the flood subsides—in other words, will spread the effect of the flood over a longer period without affecting the total amount of water sent down.

A moderate increase of the carrying capacity of the river channel may be made by judicious improvements in its bed, but it must be distinctly recognised that no great amount of relief can be obtained in this manner except at a cost far in excess of that of any of the schemes as yet brought forward.

I am bound to say that I am absolutely sceptical as to the value in this connection of increased waterway obtained by deep dredging; this space being occupied by sea water which has to be pushed back before it can become available for the discharge of river water, must always be exceedingly ineffective for the latter purpose, especially with a rising tide. That some increase of discharging power can be obtained in this way there is no doubt, but it will be very slight in proportion to the increased area of waterway. I must add that the actual discharging power of a given section under such conditions as those with which we have to deal is very largely a matter of conjecture, and is not by any means the matter of simple calculation which most of those who have dealt with the question assume.

The first question to be considered is what is the maximum quantity of river water with which we must be prepared to deal. Mr. Henderson estimates this at 24,000,000 of cubic feet per minute, or 400,000 cubic feet per second but I must confess that I find it impossible to accept this estimate,

which is based on observations of surface velocity, to which is applied a coefficient of correction in order to obtain the mean velocity. Now, in India, where we have a very wide and very long continued experience of work of this class, it has been found that estimates of discharge made in this manner invariably tend to err on the side of excess, the fact being that in a natural river, as distinguished from a canal or a river artificially regulated and straightened, the ratio of the mean to the maximum velocity is very much less than is indicated by the formulæ given in text books. Every bend, every obstruction, every irregularity of any kind tends to reduce the discharge, and where there are eddies or back waters (as there are in almost all streams) a considerable portion of the section is not only non-effective but sometimes its effect is actually negative.

It may be said broadly that all sources of error tend in the direction of over-estimation, and this is especially the case in a river like the lower Brisbane, which has an exceedingly tortuous course (a fruitful source of eddies and back waters) and is filled with obstructions of all sorts, while its bed is of unusually varying section, and is partially occupied by sea water.

An interesting instance of the effect of this pre-occupation of a river bed is found at the junction of the Stanley and Brisbane rivers, where the former having been in heavy flood before the latter had "headed up" and occupied its bed for some miles above the junction, with the result that when the flood came down the latter it rose to a height far in excess of what would have been required to discharge it if the bed had been free.

Apart from all this, formulæ such as those used by Mr. Henderson, are applicable only to streams in which the flow is continuous and unobstructed for some distance above and below the point of observation, and are utterly inapplicable to such cases as this, where a large portion of the waterway is already occupied by water coming in independently of the river, and either inactive or actually opposed to the discharge of the water. Observations of surface velocities in such a case are not only inconclusive, but absolutely worthless, and the only trustworthy method of obtaining the discharge at a given period would be by means of current meters fixed at a large number of points in the cross section, and to be of any use they would have to be so numerous as to be practically impossible.

It has been found in India that the only trustworthy method of measuring the discharge of a large river is by observations taken at a place where its flow is concentrated and controlled, as at a large bridge, or at a weir of a class common in the great irrigation works, and even here the observations to be of real value must be numerous, and extend over a considerable period.

Fortunately, works of the class in question are so numerous and their records so completely kept that we have accumulated an enormous mass of information on this point, and the result of this experience is to enable us to estimate with a reasonable amount of accuracy the maximum discharge to be expected from a river of which we have no direct measurements, but of which the drainage area and the general physical conditions are known.

In dealing with such a river we prefer to estimate its probable maximum from the known drainage area of the basin, with due consideration of its physical and meteorological conditions.

In the case of the Brisbane this method is really the only one available, as the observations actually made are, for the reasons already stated, entirely untrustworthy, and I cannot find that any observations have been recorded at a point above tidal influence, where they would have some value.

It will readily be understood that the maximum rate of discharge from two given areas under similar conditions will not be directly proportional to their areas—that is, that the maximum discharge from an area of 1,000 square miles will not be ten times that from an area of 100, but that the larger area will have a proportionately less rate than the smaller, as the rainfall will take longer to reach the main stream, and there is less probability of the whole area being subjected to a maximum rainfall at the same time: in other words, the maximum flood to be provided for will not be proportional to the drainage area, but to some function of the latter, less than unity.

In the South of India we have found that this function is two-thirds—that is, that the maximum discharge in cubic feet per second to be expected from a drainage area of M square miles may be represented by $cM^{\frac{2}{3}}$ where c is a numerical coefficient depending on the physical, geological, and climatic conditions of the drainage area being dealt with.

Attempts have been made to introduce other more complicated formulæ to allow for the different causes which affect the rate of discharge, but all experience goes to show that none of them give results as trustworthy as the simple formula which I have quoted, if the latter be properly used—a very important proviso.

Omitting small areas entirely in hill tracts, for which larger coefficients are required, the coefficient c in the rivers of Southern India varies from 400 to 800 according to a variety of circumstances, all of which must be taken into consideration, and there is no point connected with hydraulic engineering on a large scale which calls for more judgment and thought on the part of the engineer than the selection of the coefficient to be employed in the absence of direct and trustworthy records, as upon this depends primarily the design of any work contemplated in connection with a river, and an error in one direction means unnecessary expenditure, while an error in the other direction may mean disaster.

In rivers of the class under consideration I have never known one whose maximum recorded flood (recorded under conditions which enabled a fairly accurate measurement to be made) would require a coefficient exceeding 800.

No one will deny that it would be exceedingly dangerous to apply conclusions drawn from observations of rivers under one set of conditions to a river under different conditions, but in my study of this question nothing has struck me more forcibly than the extraordinary similarity of the meteorological, topographical, and geological conditions of the Brisbane Valley to those of the rivers of Southern India, which take their rise in the Western Ghats and flow towards the east coast, especially the Palar, the Vaigai, and the Tambrapurni.

I cannot believe that the Brisbane River, in the lower part of its course, would bring down more water in proportion to its drainage area than any of those three rivers, which have coefficients of 714, 720, and 742 respectively; but taking the higher coefficient of 800 as applied to the Brisbane area of 5,185 square miles, the maximum discharge to be expected would be just 240,000 cubic feet per second; and a careful study of the whole of the evidence leads me to the conclusion that the actual discharge during February, 1893, could not possibly have exceeded this amount.

The diagrams C and C¹, referred to on page 4 of Mr. Henderson's Report, give—with what appears to be a considerable approach to accuracy—the estimated amount of the rain which fell over the whole basin during the floods of February, 1893; and a comparison of these diagrams with Mr. Henderson's estimate of the discharge of the river at the same time shows that the water must have run off in the first flood 65 per cent., and in the latter 85 per cent., of the total fall in order to give that discharge.

The largest percentage of rain which I have ever seen discharged by anything except a mountain torrent was 55 per cent., and this was from a small basin of 300 square miles in a hilly country whence the main stream had a fall of 30 feet per mile, and the tributaries anything from that to 1,000 feet, and I do not believe that anywhere in the world has a basin of 5,000 square miles ever run off in five days as much as 35 per cent. of the rain falling on it in that time.

This percentage applied to the quantities given in diagram C would give a maximum discharge of about 220,000 cubic feet per second, and a total of about 66,000 millions of cubic feet during the five days.

Again, an examination of the levels of the river during this same flood shows that when the latter was at its highest the average cross section of the waterway during the first five miles below the Victoria Bridge varied from 48,000 to 34,000 square feet, and that the average was rather under 39,000 square feet, of which about 20,000 square feet, or rather more than half, was below, and 19,000 square feet above mean sea level—so that if the discharge was 400,000 cubic feet a second, the mean velocity must have been 10.25 feet per second, or 85 per cent. of the maximum surface velocity observed, which is the proportion given on page 5 of Mr. Henderson's Report.

Considering the nature of the river, and that rather more than half the waterway was permanently occupied by sea water, which had to be pushed back before any outward velocity could be developed, it is quite certain that the mean velocity could not have exceeded one half the maximum surface velocity, and was probably less; this would give a discharge not exceeding 234,000 cubic feet per second.

These remarks refer to the discharging power of the river with the tide water at mean sea level. The actual discharge varies from time to time with the state of the tide, being of course greater at low tide than at high, and probably, for any given level of tide, rather greater on the ebb than in the flood, but these variations are in their nature temporary, and are in any case very small as compared with the total river discharge.

The conclusion seems irresistible that the discharge in this flood could not have reached 240,000 cubic feet per second, and I believe that we should be quite safe in taking this amount as the maximum to be provided for, but as it is not certain that a still higher flood than that of February, 1893, may not occur in the future, I propose to take the maximum at 270,000 cubic feet per second.

The next question is, What proportion of this discharge can be safely sent down the river? Mr. Henderson (page 7) assumes that only 38,057 millions of cubic feet could be sent down in seven days, and that the balance of the volume of the 118,049 millions at which he estimates the total discharge during that period, must be stored; but this estimate is based on a misapprehension. It is quite certain that if the maximum discharge was 400,000 cubic feet per second (the basis on which the estimated total of 118,049 millions is founded), the river in its present condition could carry with safety at least 180,000 cubic feet per second; and this during seven days would amount to 108,864 millions, leaving the amount to be stored only 9,185 millions—a very different matter from 80,000 millions—with no improvement to the water bed.

In point of fact, however, this method of calculation is wrong in principle, as what we have to deal with is not the total discharge during a flood, but the discharge during the period when the safe carrying power of the river is exceeded; and for this it is necessary to have a record of the levels of the river at short intervals throughout the duration of the flood. Unfortunately no information on this point is available, no records of the rise and fall of the river at any one point having been kept, but an approximation to the actual facts can be obtained by consulting Mr. Henderson's diagrams C and C¹, which, though useless as actual records of quantities, probably represent with some approach to accuracy the manner in which the flood rose and fell, and correspond fairly with actual records of the course of floods in other rivers.

Taking the ordinates in Diagram C to represent discharges in cubic feet per second, and the ordinate at the highest point on the curve to represent the maximum estimated rate of 270,000 cubic feet per second, the distance between the horizontal lines on the diagram will each represent a discharge of 10,800 cubic feet per second, and taking the abscissæ to represent periods of three hours, the area contained in one of the small rectangles into which the diagram is divided will represent $10,800 \times 3 \times 60 \times 60 = 116,64$, or say in round numbers 120 millions of cubic feet.

If we draw a horizontal line at the height representing the discharge which the river can safely be allowed to carry, the area between that line and the one above will represent (on the scale of 120 millions of cubic feet to each rectangle), the total quantity to be stored.

The following table shows what this quantity will be for various rates of discharge down the river:—

Maximum Rate of Discharge permissible in the River. Cubic Feet per Second.	Storage required in Reservoir. Millions of Cubic Feet.
130,000	22,500
140,000	20,000
150,000	18,000
160,000	16,000
170,000	13,000
180,000	11,000

Although no records of the levels of the floods of 1893 at different times have been kept, such records have been kept of the smaller flood of January, 1898, and, making a proportional increase in the ordinates of the curve of this flood to bring the maximum discharge to 270,000 cubic feet a second, the amounts required to be stored are almost exactly the same as those given in the above table, which is in accordance with the well-known fact that the curves of discharge of all floods in the same river are of very much the same description, though varying in magnitude.

It may, I think, be accepted that a maximum level of 15 feet above low water datum at Norman Wharf and of 19 feet at the Victoria Bridge can be allowed without inconvenience or danger. It is not an easy matter to say precisely what the river can discharge at these levels in its present condition. The discharge is somewhat reduced by the very insufficient waterway at certain points for the first five miles below the Victoria Bridge, especially at cross sections Nos. 1, 3, and 5 on Mr. Henderson's Drawing No. 5; but assuming that the discharge in February, 1893, reached a maximum of 240,000 cubic feet per second, with an area of waterway which, as already stated, averaged 39,000 square feet, of which 20,000 was below and 19,000 above mean sea level, a reduction of the levels to those contemplated would reduce the average waterway to about 30,000 square feet, or 77 per cent. of its area during that flood. This reduction would, however, be entirely in the upper and more efficient portion of the area, and probably the mean velocity would not exceed about $4\frac{1}{2}$ feet per second, giving a discharge of 135,000 cubic feet per second, as against the maximum of 240,000.

The only improvements to the river at Brisbane which I consider necessary are a widening of 300 feet at Garden and Kangaroo Points, of 200 feet at Kinellan, and 150 feet at Norris and Bulimba Points, and the making up of the banks as far as possible to 15 above low water level from the lower end of Bulimba Reach to Kangaroo Point, and from that to 20 feet at the Victoria Bridge. This latter is not a matter of vital importance, and it may not be possible to do it at once with due regard to existing interests, but it should be looked upon as an object to be held in view. At present there are many places where the banks are so low that a very moderate flood is sufficient to pass over them, and where they can be raised without any danger.

The widening of the points need not, so far as flood regulation is concerned, be carried lower than 20 feet below low water datum, but it may be desirable to carry it somewhat deeper in the interests of navigation.

This will give additional waterway just where it is most needed. It is difficult to estimate the cost of the work, as so much depends on the price to be paid for land, but the ground is low and the soil easy, so that it ought not to exceed the £100,000 which I have allowed.

The other improvements proposed in connection with marine interests will not have much effect, and the total result will probably be a lowering of the levels of such a flood as that of 1893 by 3 or 4 feet at Norman Wharf, and an increase of the amount that can be carried by the river with the levels considered safe, from 135,000 cubic feet per second to about 150,000.

I am inclined to think that the narrowing of Hamilton Reach is being carried rather too far, but the point is not one on which I can speak positively, and the effect on flood discharge will not be serious.

I have read with much care so much of Mr. Lindon Bates's Report on the rivers and harbours of Queensland as refers to the Brisbane River, but have not derived from it any information of value in dealing with this question. His reference to the Fitzroy spillway at Rockhampton as a matter "meriting notice during the reconsideration of the diversion and reservoir question" can hardly be meant to be taken seriously. The spillway in question is a natural outlet, nothing corresponding to which exists in the Brisbane, and the artificial provision of such a spillway is the object of some of these schemes for diversion canals, which have been properly condemned by Mr. Henderson.

With the flood level at Victoria Bridge reduced to 19 feet above the low water datum, and the maximum discharge limited to 150,000 cubic feet per second, I do not think any necessity will be found for improvement above the bridge, and I have therefore made no provision on this account.

I do not consider any special measures necessary in connection with Norman or Breakfast Creeks. With the levels lowered and the discharge of the main river reduced as now proposed, no serious results can arise from their action.

We may now proceed to consider how best to provide storage for the discharge of the river over and above 150,000 cubic feet per second—that is to say, for 18,000 millions of cubic feet of water, at a point as high up the river valley as possible. As high up as possible, because the higher it is the more complete will be the protection afforded to those lands which are now flooded by abnormal rises in the river level, and the less will be the quantity of flood water to be controlled. It is not, however, advisable to go above the junction of the Brisbane and Stanley Rivers, as the ground is much less favourable for the construction of a large reservoir than is the case below the junction; and it is doubtful whether, under certain conditions, the closure of the whole of one of those rivers would give the necessary relief to the lower Brisbane, so that it would probably be necessary to have two reservoirs, one on each branch, the aggregate content of the two being at least half as much again as that of the single reservoir below the junction.

The site selected is about seventeen miles below the junction of the two rivers, and is, I think, on the whole the best possible. For some reasons I should have preferred a site somewhat nearer to the junction, but there is none equally favourable with that chosen, which has been selected by Mr. Henderson after a careful examination of the valley, and which I agree with him is considerably the best.

The site is in fact an admirable one, and the local conditions are singularly favourable for the construction of a dam of moderate height.

The sills of the discharging sluices at this site can hardly be placed at a lower level than 140 on the datum of the surveys, and to give a storage of 18,000 millions of cubic feet above this level the maximum water level in the reservoir must be about 100 feet above the sluice sill, or 240 feet above the datum, and 120 feet above the lowest part of the river bed at the site of the dam.

The conditions for the formation of a large reservoir are, however, so favourable that it seems desirable to take advantage of them in order to increase the capacity of the reservoir by making it slightly deeper, and so giving increased security. An addition of 10 feet to the height of the dam will increase the storage capacity from 18,000 millions of cubic feet to about 25,000 millions, and the works have been designed for this level.

That the 18,000 millions provided by the lower dam would be practically sufficient for safety I fully believe, but it must be borne in mind that in calculations of flood discharges there must always be an element of uncertainty, and the engineer who has had the greatest experience in dealing with river floods will be the last to claim infallibility for his opinion as to the probable course of a flood in a large river. The extra cost is small as compared with the extra security given by the higher dam.

An additional reason for providing an amount of storage somewhat in excess of that absolutely necessary is found in the possibility of the reservoir being used in the future for purposes of irrigation. I shall refer to this question later on, but may say here that if the storage is limited to the 18,000 millions of cubic feet which I consider the minimum necessary for safety, it must be rigidly reserved for this purpose, and the reservoir be peremptorily emptied before the beginning of each rainy season, no matter how much local interests may suffer thereby. If the larger reservoir is adopted, much greater latitude may be allowed.

As regards construction, the dam must be of masonry or concrete. Even if an earthen dam were the cheaper, it could not be recommended for a work of this magnitude, but in point of fact it would, in my opinion, be very much the more costly of the two. For reasons which will be explained later on, the sluices for keeping the reservoir empty until it is required for the regulation of floods, must extend across the whole width of the valley. These sluices must be of masonry, and with an earthen dam must be at least 500 feet in length (in the direction of the flow of the river) as against the 90 feet or so required for a masonry dam, and as their foundation is the most costly and difficult part of the whole work, the extra cost of the sluices would more than swallow up any saving which might be effected by the use of earth instead of masonry in the upper part of the dam. The matter is in fact one that does not admit of discussion: the idea of the construction of an earthen dam in this case cannot be entertained for a moment, so far as the central portion of the dam is concerned, though there is no objection to it for the flank portions where the depth of water does not exceed 50 feet, and it may possibly—though I think not probably—be found advisable to substitute earth for masonry for this portion of the right flank.

The construction to be adopted should be that which has been so successfully used in the Periyar Dam—at present, I believe, the highest, and forming the largest artificial lake in the world—namely, a body of concrete with a skin of rubble masonry on each face, the rubble forming from one-fourth to one-third of the whole quantity. It must be uncoursed rubble—the rougher and more irregular the better. Except in the sides of the sluices, nothing in the shape of ashlar is wanted; and anything in the shape of a “course” should be looked upon as absolutely inadmissible. The Periyar Dam contains some 6,000,000 of cubic feet of masonry and concrete; and there is not a particle of coursed or dressed stone from one end to the other, except the memorial stone containing the dates of commencement and completion.

This dam will differ from any high dam with which I am acquainted in the very large amount of sluiceway required for the passage of water beneath it; being, in this matter, comparable rather with such works as the Caverry and Vennar regulators in the South of India, which are of no great height, than with the dams of ordinary storage reservoirs.

In order that the full content of the reservoir may be available for the storage of abnormal floods, it is necessary that not merely the average discharge of the river at the site of construction, but something much more than that, should be capable of being freely passed through the sluices, and no part of this inquiry has required more thought than the decision as to what the discharging capacity of the sluices should be.

The drainage area of the river at the site of the dam is about 2,600 square miles, and the average discharge is probably something like 5,000 cubic feet per second, falling to next to nothing in seasons of drought, and rising to 80,000 cubic feet per second in heavy floods, and perhaps to double this amount on abnormal occasions. I do not think it is ever likely to exceed this latter figure of 160,000 cubic feet per second.

It will, I think, be conceded by anyone who has studied the rainfall records and the topography of the basin that the lower Brisbane is never likely to be in abnormal flood (and it is with abnormal floods alone that we are here concerned) unless the Stanley and Upper Brisbane are in the same condition. Now, by the terms of our problem, when this state of things occurs we have to reduce the rate of discharge in the lower Brisbane from 270,000 cubic feet per second to 150,000—in other words, that we have to store in the reservoir a maximum amount of 120,000 cubic feet per second, and as the river at the site of the dam may at this time be discharging 160,000 cubic feet per second, the balance, or 40,000 cubic feet per second, must be passed through the sluices. This is one condition to be met; another is that the sluices shall be of sufficient capacity to prevent an accumulation of water in the reservoir from the action of the upper river alone, which will seriously interfere with its regulating capacity when the whole basin is in flood. What this should be is a matter which is almost incapable of definite statement, and must be decided on personal judgment. Looking to the fact that when the upper river is in heavy flood the reservoir will almost always be wanted to hold back some of its discharge, I think that for this purpose a discharging power of 50,000 cubic feet per second will be ample.

A third condition is that the sluices should be capable of emptying the reservoir in a period not exceeding eight days, the river at the same time discharging at four times its average rate, or 20,000 cubic feet per second. This is in order to provide for the contingency of two heavy floods following each other at a short interval, as happened in 1893.

Twenty-five thousand millions of cubic feet in eight days is 36,169 cubic feet per second, so that for this purpose $36,169 + 20,000 = 56,169$ cubic feet per second will be the discharge required.

Sixty thousand cubic feet per second will therefore be an ample allowance for all purposes, and experience has shown that a velocity of 20 feet per second can be borne for long periods without injuring masonry of the class proposed to be used in these works, and that 25 feet per second, or even more, can safely be allowed for short periods. I think it will be enough if the area of sluiceway given is 3,000 square feet, which will leave an ample margin for contingencies, as the velocity of 20 feet per second can be obtained when the water level is only about 30 feet above the sluice sills, absorbing rather less than one-sixtieth of the content of the reservoir.

The regulation of the discharge according to requirements will be provided for by gates and gearing, the details of which need not be discussed here, and I do not propose in this Report to enter into any further details of construction, which are matters for the engineer entrusted with the execution of the work, and with which I have no doubt he will be competent to deal. With such details it would be useless to encumber a Report of this kind, but a separate note on the design of the dam will be prepared for the information of the engineer if the execution of the works is decided on, and I shall be happy to answer any questions concerning them which may be put to me by the Government of the colony and its professional advisers.

Page 8 of Mr. Henderson's Report contains certain pertinent remarks on the necessity of rules regarding the control of the sluices of a regulating reservoir. This is rather a matter of administration than of engineering, but I would strongly urge that the absolute control of the regulation be placed in the hands of an individual who shall be empowered and bound to act solely in the public interests without regard to any private interests whatever; legislation for his protection being resorted to if necessary.

If irrigation is not carried on, he should be bound to empty the reservoir completely, so far as the natural flow of water in the river will allow, by a certain date, and not to allow it to fill before another date, both of which should be fixed by law or by Executive order.

If irrigation is adopted, he should be bound to keep the water level down to 200 above datum between these dates, except when the reservoir is used for its primary purpose of flood regulation, and should be empowered, though not bound, to empty it still further if he considers it advisable to do so.

More detailed regulations will of course be worked out as experience is gained, but some such fundamental limitations as are here sketched will be absolutely necessary, and it must not be forgotten that the measures under consideration are required for abnormal conditions which may only occur at long intervals, and because they may be found unnecessary for ten years in succession they should not be relaxed; if they are, a disaster will certainly occur in the eleventh year.

I would strongly urge that early steps be taken to establish a continuous series of records of discharges at a point as low down the river as possible without coming under tidal influence, and that the levels and discharges thus obtained be compared with the levels at the same time at some point in the city; the Victoria Bridge would be as convenient a point as any. It would then be possible to ascertain with some degree of accuracy what is the actual discharge corresponding to any given level at the latter point, a question on which I am bound to say absolutely nothing appears to be definitely known at present. This knowledge would be of the greatest use in connection with the control of the regulating reservoir.

After inspection of the river valley, I consider that the best place for a permanent gauge would be just below the Lunatic Asylum at Goodna, at a site which I have pointed out to Mr. Henderson, and shall be prepared, if desired, to draw up notes for the record of the observations and to select the apparatus required.

This point is not quite free of tidal influence, but the latter is very slight.

A similar record should be kept at the pumping station at Ipswich, where great facilities already exist.

It will be seen that the proposals now made differ from those sketched in my note of the 10th October, 1898, in the entire omission of any provision for a diversion channel, and in the much greater stress laid upon storage as compared with improvements to the river bed. This is due to further study of the subject, which has increased the doubts I had always felt as to the efficiency of the last-mentioned method of dealing with the question, to the detailed information and surveys received since that note was written, and to personal inspection of the locality, which shows the conditions for the construction of a large reservoir to be even more favourable than I had ventured to hope.

The total cost of the works now recommended is estimated at £1,300,000, including the cost of engineering supervision, special plant, and land, but not that of parliamentary or legislative expenses, concerning which I am not in a position to give an opinion of any value.

With regard to the land, I have made the best estimate I can with a limited knowledge of the country. The area liable to submersion will be about 19,000 acres, but if the cost of land is high it is not absolutely necessary to acquire the whole of this; the greater part of it would be very rarely submerged, and it would probably be possible to arrange that it should remain in the hands of its present owners, the Government paying the value of any damage done by submersion, which would probably be cheaper than acquiring it outright. Nevertheless, I believe it would be better to acquire it permanently, and to re-lease it to the present owners or others, on terms which would secure the Government against claims for compensation on account of submersion. I do not think the net cost should exceed the £80,000 which I have allowed. It must be borne in mind, in considering the question of compensation, that quite one-third of the total area of 19,000 acres is already liable to submersion, and that the liability of this portion will be but little if at all increased by the construction of the reservoir, while the latter will preserve at least 90,000 acres lower down which are now liable to submersion.

The reservoir when filled will submerge a portion of the road from Woodford to Esk, including the bridge over the Brisbane a little below Caboonbah; but this bridge and a portion of the road leading to it is already liable to submersion in very moderate floods, and as the reservoir will only be brought into use in high floods, it is doubtful whether in an average year its construction will increase the period of this submersion by twenty-four hours. I would, however, recommend that the existing bridge should be raised 20 feet, and the road leading to it correspondingly diverted, which will certainly render it less liable to submersion, even after the construction of the dam, than it is at present. At the same time, I would advise that an additional diversion should be made from this road on each side to the site of the dam (in the design for which a roadway is included), which will give a route always available, and only five miles longer than the existing one. The cost of this, which is included in the estimate, will not exceed £18,000 at the outside; and as it will remove all cause for complaint on this score by the land-owners on the bank of the river, it will be money well spent.

The question of irrigation is outside the scope of my inquiries, but it has been impossible to avoid alluding to it, as it seems almost certain to be raised in connection with the construction of a reservoir such as is here contemplated. I can only say that there seems a good deal to be said in favour of taking advantage of this opportunity of mitigating the drought which so frequently occurs in this country, and that a great deal can be done in this direction without in the least interfering with the primary object for which the works were undertaken, which must of course be held supreme.

Financially the two objects must be kept entirely separate. The protection of the river valley and of the capital city from the effects of floods is an object of general interest, the cost of which may be legitimately met from general revenue. The utilisation of the water for irrigation is a matter of purely local interest, and any additional expenditure with the object must presumably be met, or the interest on it paid, by those interested. This additional expenditure will in any case be very small.

It will be seen that the total cost falls considerably short of the £1,500,000 sterling in the first of my letters, included with the papers ordered to be printed on the 20th May, 1899, I indicated as the probable sum which would have to be provided.

I trust that the proposals now made will meet with the approval of the Government of the colony: that they will meet the object in view I have no doubt whatever, and if the works are properly constructed they will involve no risk of any kind. Looking to the distress caused by the present state of affairs, their cost does not appear to be excessive.

It must not be supposed that their construction will be a small matter or one to be carelessly undertaken: that it will present difficulties requiring the greatest skill, energy, and devotion on the part of those entrusted with the execution of the works is undeniable, but these difficulties are not greater than have been successfully dealt with in many other places, and there need be no question of the qualifications required being at the disposal of the Government of the colony.

In conclusion, I desire to express my grateful acknowledgments for the courteous assistance I have received from those officials and other residents in the colony with whom I have been brought in contact in connection with this most interesting duty, and especially to Mr. Henderson, to whom I owe something more than a mere expression of thanks for personal courtesy. It may be said that it is no part of my duty to criticise, however favourably, the action of any local official, but at the risk of exposing myself to the charge of going beyond my province, I must express my admiration of the manner in which Mr. Henderson has carried out the preliminary investigations asked for in my note of 10th October, 1898. It is not too much to say that, but for this and the information contained in his admirable reports, it would have been impossible for me to have dealt satisfactorily with the question.

The following drawings accompany this Report:—

1. General Plan of Reservoir.
2. Enlarged Plan of Site of Dam.
3. Cross-section of River at Site of Dam.
- 4 and 5. Plan and Sections of Dam.

JOHN PENNYCUICK, Colonel, R.E.

Brisbane, 22nd November, 1899.

ESTIMATE.

Dam.	£
2,200,000 Cubic feet of rubble masonry in cement, at 2s. 6d.	275,000
4,400,000 Cubic feet concrete in cement, at 2s.	440,000
7,000 Cubic feet of ashlar for quoins of sluices, at 5s.	1,750
96,000 Cubic feet of dry stone paving in front and rear of dam, at 1s.	4,800
2,000 Running feet of dry stone drains 3 feet by 3 feet, at 10s. per foot	1,000
2,000 Running feet of dry stone drains 1½ feet by 1 foot, at 5s. per foot	500
100,000 Cubic yards of excavation for foundation in flanks of dam, including refilling where necessary, at 4s. 6d. per cubic yard	22,500
950 Running feet of roadway, at £6 per foot	5,700
400 Running feet of platform for working sluices, at £3 per foot	1,200
50 Sets of sluices, openings 7½ feet by 8 feet, with gearing for working, at £600 each	30,000
3,000 Running feet of steel rails, 60 lb. to the yard, for protecting the entrance to sluices, at £15 per ton	400
Excavation in river bed, coffer dams and pumping	80,000
Special plant and machinery	60,000
Diversion of road and improvements to bridge	10,000
Compensation for land occupied by reservoir	80,000
Temporary buildings	10,000
Engineering supervision	50,000
Contingencies	127,150
Total for construction of regulating reservoir	£1,200,000
Improvements to river at Brisbane	100,000
Total	£1,300,000

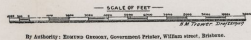
Price 5s. 5d.]

By Authority: EDMUND GREGORY, Government Printer, William street, Brisbane.

BRISBANE RIVER

Showing proposed Improvements
recommended by Marine Department
and approved by
LINDON W BATES

*of Public Works, in Dept. C.E.
General Engineer*



SOUTH
BRISBANE

NORTH BRISBANE

KANGAROO POINT
NEW FARM
BULimba

HAMILTON

QUEENSTOWN

BULWER ISLAND

GIBSON ISLAND

MYRTLE

SUMMARY

Gardens, Kangaroo, Kinellon, and Bulimba Points to be cut away.
Aggregates. Areas—581 acres
Quantities—31 million c. yds. (to 21 below L.W.)
Waterway to be 500' wide and 26' deep at L.W.S.
Quantities. Dredging—15 million c. yds.
Rock excavation—130,000 c. yds.
Training Walls to be as shown.
Quantities—831,865 c. yds.

NOTES.

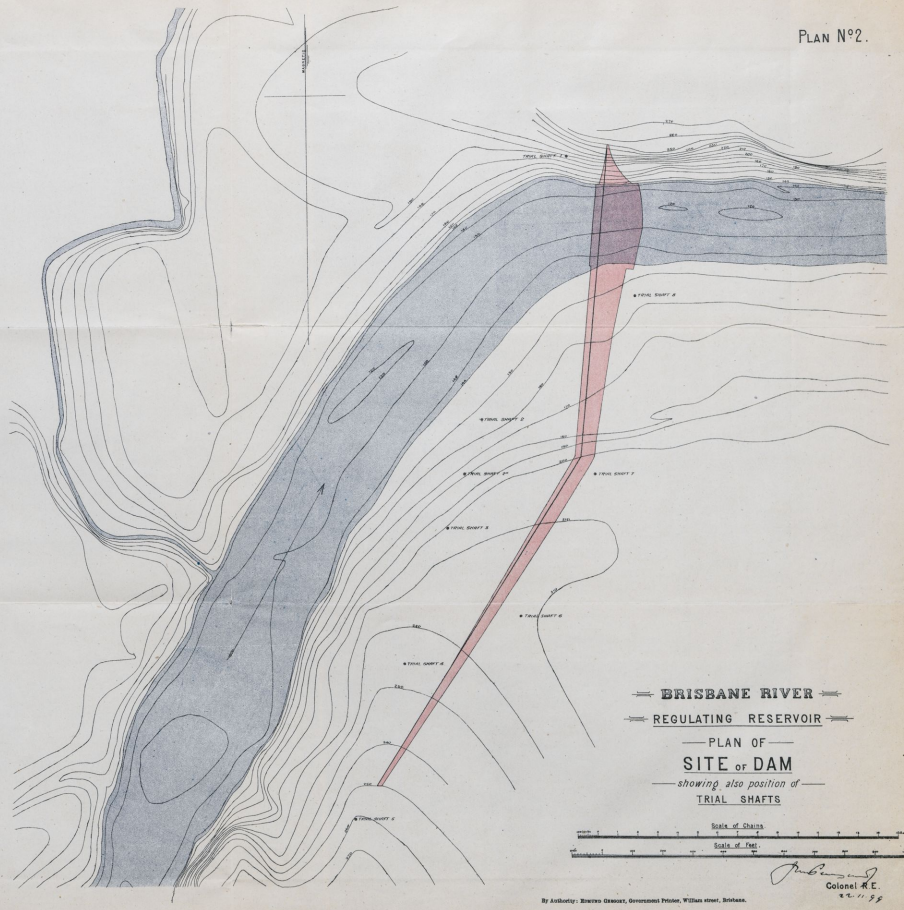
Points to be cut off ... tinted Red
Depositing Ground ... Brown.
Cuttings ... hatched in Red.

AREAS UNDER TIDAL INFLUENCE

Brisbane River and tributaries above Victoria Bridge	ACRES
— from Victoria Bridge to 124444 ft (exclusive of tributaries & areas behind walls etc)	23.02
Norman Creek	26.41
Breakfast	2.0
Inside Hamilton wall	50
— Tucker Island	27.0
— Douglas Creek	250
— Inside Fisherman Island	70
Aqueduct Passage	455
Inside Bulwer Island	100
Total below Bridge	700
	4486

*Trimmer
Bates*

ST HELENA IS



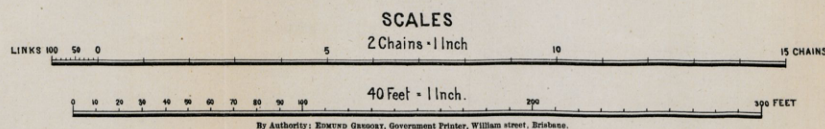
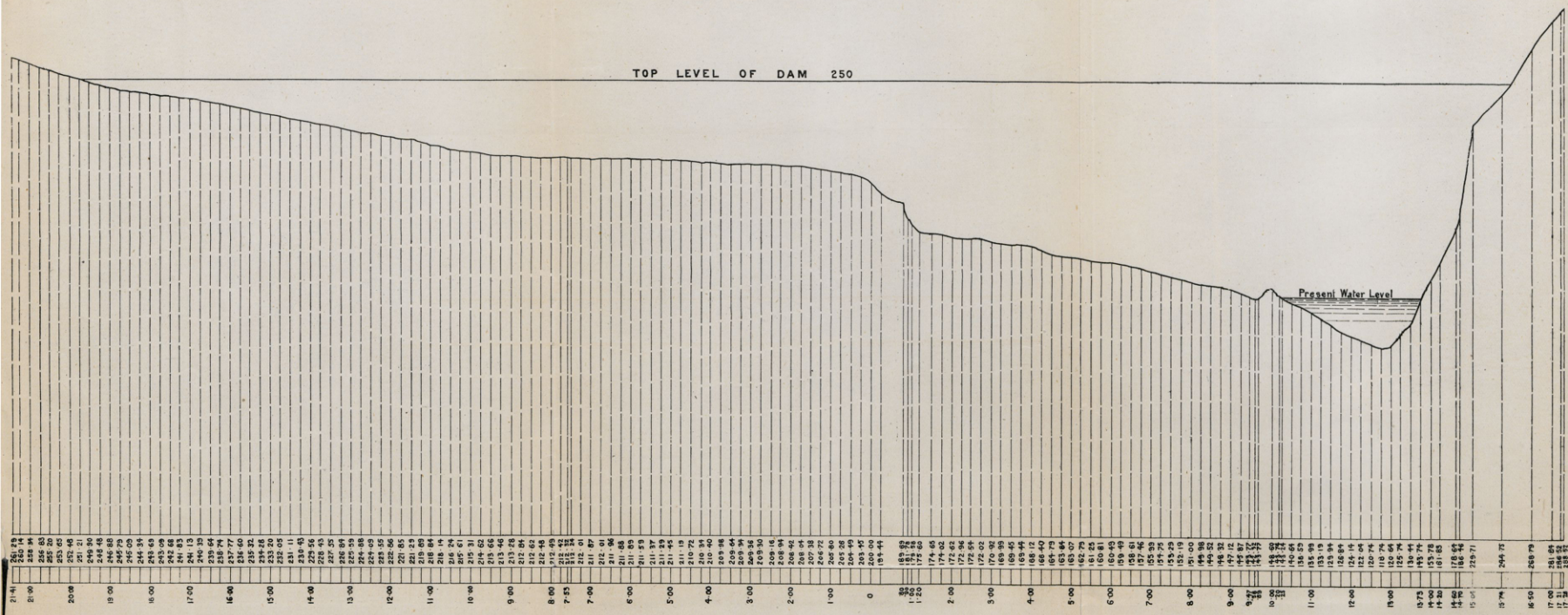
BRISBANE RIVER

REGULATING RESERVOIR

PLAN N^o3.

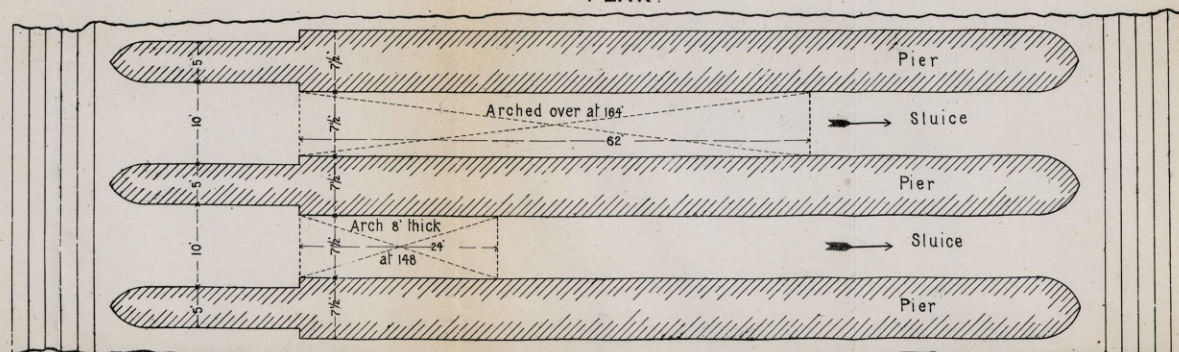
CROSS SECTION OF RIVER

— AT —
SITE OF DAM.



James
Colonel R.E.
22/11/94

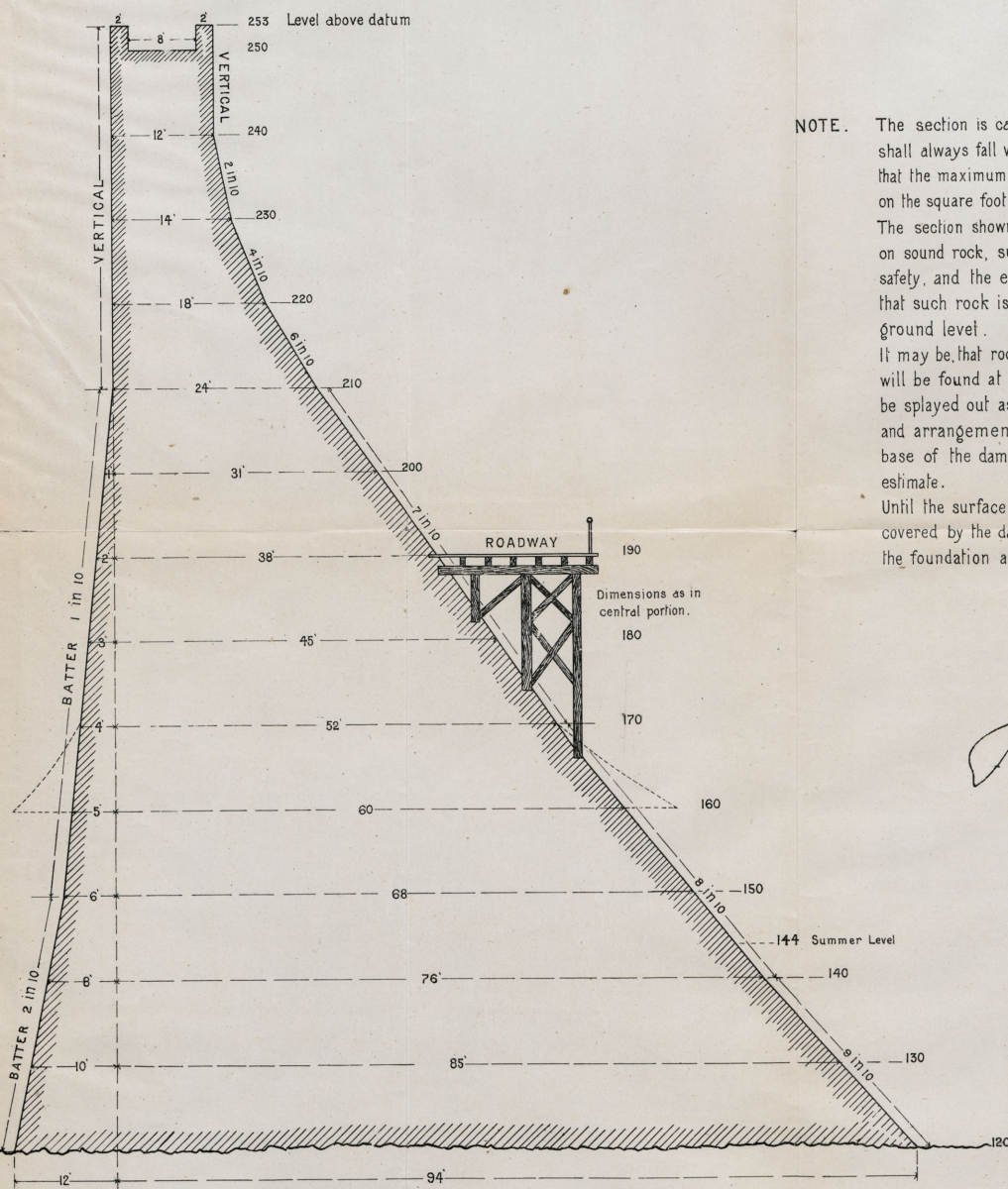
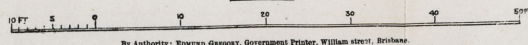
22-11-55



= BRISBANE RIVER =
= REGULATING RESERVOIR =

SECTION
— OF —
FLANK PORTIONS OF DAM.

SCALE.



NOTE. The section is calculated so that the lines of pressure shall always fall within the middle third of the dam, and that the maximum pressure shall not exceed 18,000 pounds on the square foot.

The section shown is that to be adopted when the base rests on sound rock, sufficiently hard to take this pressure with safety, and the estimate is calculated on the supposition that such rock is found at from 20 to 30 feet below the ground level.

It may be, that rock not quite sound, but safe to build on will be found at a less depth; in this case the base must be splayed out as shown by the dotted lines at level 160, and arrangements may have to be made for draining the base of the dam; the latter are provided for in the estimate.

Until the surface soil has been removed over the whole area covered by the dam, it is impossible to say precisely what the foundation arrangements must be.

Robertson

Colonel R.E.

22-11-99